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PERFORMANCE ASSESSMENT OF A VENTILATED MATTRESS FOR POLLUTION CONTROL OF THE BED MICROENVIRONMENT IN HEALTHCARE FACILITIES

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SUMMARY

A new method for minimizing the spread of bioeffluents emitted from hospitalized patients lying in beds was developed and studied. The method consists of a ventilated bed mattress that is able to exhaust the human bioeffluents at the area of the body where generated before spreading around in room. Full-scale experiments were conducted in a climate chamber furnished as a two-bed hospital patient room. A thermal manikin and two heated dummies were used to simulate two lying patients and a standing doctor. The bed with the thermal manikin had the ventilated mattress (VM). The tracer gases CO_2 and N_2O were used to mimic human bioeffluents released from the feet and armpits of the manikin, respectively. The concentration of the tracer gases was measured in six points including the breathing zone of the simulated occupants. The results show that the VM combined with mixing ventilation at 1.5 air changes per hour (ACH) proved to be more effective in reducing exposure to body contaminants compared to mixing ventilation alone at 3 ACH and 6 ACH. The findings also show that the lying position and the size of the local exhaust of the VM affect the efficiency of the mattress to exhaust bioeffluents.

INTRODUCTION

People create a microenvironment when lying or sleeping in bed. The mattress, pillows, bedding, the people including their breathing and the convective flow established around the body all together form the bed microenvironment. The generated bed microenvironment can be a source of pollution. A variety of volatile compounds can be emitted from several areas of the human body that are prone to odour production, e.g., scalp, armpits, feet, groin, and oral cavity (Pandey and Kim, 2011). In hospitals and other healthcare functional facilities there are patients that spend considerable amount of time confined to the bed unable to frequently refreshing themselves. Thus the left on the body sweat can produce a strong unpleasant odour.

In recent years, there has been an increasing amount of studies on new air distribution methods for providing better indoor air quality. A novel method for hospital bed ventilation based on the "push and pull" air distribution principle has been developed (Melikov et al., 2011; Melikov 2011). This method comprises two devices, the hospital bed integrated ventilation and cleansing units (HBIVCUs), which are attached on both sides of the patient's bed near the head. These devices have proven to act as an efficient means to reduce the risk of airborne cross-infection in hospitals (Bolashikov 2010). However, the method might not be efficient for capturing polluted air released from the body bioeffluents while the person is lying in bed.

A new air distribution strategy for controlling the air pollution spread in the bed microenvironment has been introduced by Bivolarova et al. (2014a). The method named "Ventilated mattress" is based on source control with localized exhaust implemented within the mattress to locally extract the air pollutants before being spread in the surrounding air via the background air distribution.

The purpose of the present study is to present results on the performance of the ventilated mattress (VM) for exposure reduction to gaseous contaminants/body odours (bioeffluents). The performance of the VM was studied in a simulated two-bed hospital patient room. The VM pollutant extraction efficiency was also examined with regards to different parameters including occupant's lying position and size of the exhaust opening of the VM, which was design to be in contact with the body of the lying person.

METHODOLOGIES

Full-scale experiments were performed in a climate chamber with dimensions: 4.7 m x 5.3 m x 2.6 m (W x L x H), built in a laboratory hall, 0.7 m above the floor. The laboratory hall has a separate ventilation system and temperature control. In order to reduce the heat exchange the ambient temperature in the hall was kept the same as that in the test room. Overhead mixing air distribution (MV) was used to supply 100% outdoor air to the chamber. The outdoor air was supplied through a square diffuser mounted in the middle of the room ceiling. No recirculation was used during the experiments. The air was exhausted through two perforated square diffusers located symmetrically on the ceiling above each bed right above the head of every patient (Figure 1).

The climate chamber was furnished to simulate a two-bed hospital patient room. The distance between the beds was adjusted to be 1.06 m. On each bed with dimensions 0.9 m x 2.0 m x 0.8 m (W x L x H) there was a mattress with thickness of 0.06 m and a pillow. A thermal manikin and a heated dummy with a simplified body shape ("head", "torso" and "legs") were used to simulate lying patients in the two beds. The thermal manikin has the physics of an adult Scandinavian female with a height of 1.68 m of size 38 based on EU clothing size (10 in UK and 8 in USA). The manikin consists of 23 body parts. Each body part was individually controlled to maintain surface temperature equal to the skin temperature of an average person in a state of thermal comfort. The heated dummy lying on the second bed was adjusted to generate heat with power of 80 W. A second heated dummy (230 W) was used to simulate a doctor standing next to the manikin's bed at a 0.83 m distance from the

manikin's mouth. During the experiments the two "patients" were covered with summer duvets. The duvet was covering the whole body of each "patient" up to the neck. The thermal manikin was dressed in a short-sleeve hospital pyjama and its total clothing isolation was 0.60 Clo. The layout of the test chamber is shown in Figure 1.

The manikin was referred to as a "source patient" since it was used as a source of body emitted bioeffluents. The bioeffluents were mimicked by using a constant emission of three different tracer gases. Carbon dioxide (CO_2) and nitrous oxide (N_2O) were used to simulate emissions of bioeffluents from manikin's feet and armpits, respectively.

The ventilated mattress (VM) was placed on top of the regular mattress in the source patient's bed. The VM was used in some of the experiments to exhaust locally the contaminants emitted from the patient's body. Part of the surface of the VM is designed as an exhaust opening, from which contaminants generated from the human body (e.g. bioeffluents) were exhausted. The exhaust opening of the VM was located below the pelvis of the "source patient". The exhaust airflow rate of the VM was adjusted to be 1.5 ± 0.2 L/s during the experiments. More detailed description of the ventilated mattress and how the exhaust airflow was controlled can be found in Bivolarova et al. (2014a).

In order to optimize the performance of the ventilated mattress, two sizes of the local exhaust opening of the mattress were tested: 1) 0.8 m length x 0.16 m width equal to exhaust surface area (ESA) of 0.13 m^2 and 2) 0.4 m length x 0.16 m width equal to surface area of 0.06 m^2.

During the experiments three lying positions of the thermal manikin ("source patient") were studied. The manikin was positioned on its back in the centre of the bed and the arms placed on the side of the torso under the duvet. In the second position, the manikin was lying on its right side facing the "doctor". In the third lying position, the manikin was placed on its stomach with arms on the side of the torso. In this position the head was facing the "doctor".

Series of experiments were conducted at three background ventilation rates, namely 27, 55 and 109 L/s corresponding to 1.5, 3 and 6 air changes per hour, ACH. The room air temperature was kept at 23 ºC during the experiments. The relative humidity in the chamber was not controlled; it was measured to be within the range of 25 – 40% RH. The air mixed with the tracer gases was sampled and its gas concentration was analysed under steady-state conditions using an Innova 1303 multi-channel sampler and a photo-acoustic multi-gas monitor Innova 1312. The concentration of the three gases was measured simultaneously at 1) the mouth of the "doctor", 2) the mouth of the source patient 3) the mouth of the exposed patients, 4) the air supply diffuser, 5) the duct of the total exhaust room air, and 6) in the center of the room between the two beds and close to the source patient's feet at 1.7 m height from floor, referred to as "1.7 m center". The experiments at 1.5 ACH were performed with either the VM operating or VM not. Experiments at 3 and 6 ACH were conducted without using the VM. All experimental cases are listed in Table 1.

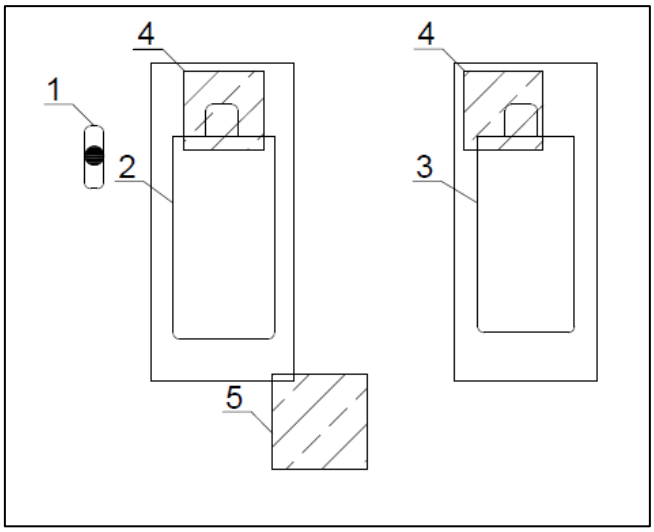


Figure 1. Top view sketch of the chamber layout: 1 – “doctor”, 2 – “source patient”, 3 – “exposed patient”, 4 – room air exhaust diffusers, 5 - air supply diffuser.

Table 1. Experimental cases.

№	Lying position of the thermal manikin	Exhaust surface area (ESA) of the VM	Background ventilation rate
1	Lying on back	*N/A	1.5 ACH
2	Lying on back	N/A	3 ACH
3	Lying on back	N/A	6 ACH
4	Lying on stomach	0.13 m^2	1.5 ACH
5	Lying on one side	0.13 m^2	1.5 ACH
6	Lying on back	0.13 m^2	1.5 ACH
7	Lying on back	0.06 m^2	1.5 ACH
8	Lying on back	1.4 m^2	1.5 ACH

*N/A – not applicable

The data were analysed by collecting 20 repeated measurements of the tracer gas concentration at all 6 measuring points after reaching a steady state concentration in the room. The median values of the concentrations were normalized according to the following equation:

$$\text{Normalized concentration} = C_i/C_{i,Ref} \quad (1)$$

where C_i is the concentration acquired at a certain measuring point, $C_{i,Ref}$ is the concentration acquired at the same measuring point during the reference condition of 1.5 ACH without using the VM. The normalization index is also referred in the text as ‘pollutant extraction efficiency’.

When the normalized concentration is less than “1” it means that the concentration obtained at the measured location (C_i) was less than the concentration at the reference point ($C_{i,Ref}$) and vice versa when the normalized concentration is higher than “1”.

RESULTS AND DISCUSSION

As shown in Figure 2, the obtained dimensionless pollution concentration released from the feet reached almost zero values when the VM was used at 1.5 ACH. Even supplying 109 L/s (6 ACH) of clean air in the room was not enough to dilute completely the simulated body released bioeffluents in the room. The highest level of bioeffluents was obtained at the mouth of the "source patient" for both conditions at 3 and 6 ACH. These results can be explained with the proximity between the point of the pollution release and the mouth of the "source patient". Also the duvet did not allow the feet bioeffluents to move directly into the room. So most of the feet bioeffluents had to move upwards towards the head (manikin was covered up to neck).

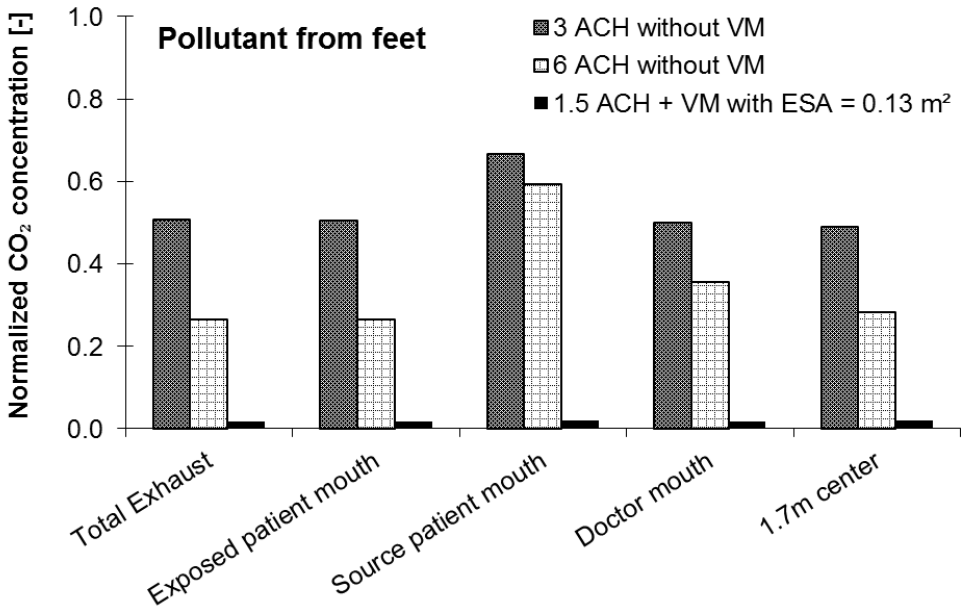


Figure 2. Comparison of the normalized concentration in the six measuring point at 1.5 ACH with the VM operating at 1.5 L/s, 3 ACH and 6 ACH without using the VM. The "source patient" was lying on its back.

The performance of the method in terms of the effectiveness to evacuate the bioeffluents from the body was examined at two sizes of the local exhaust opening. Figure 3 shows the concentration of the N_2O tracer gas released from the armpits of the thermal manikin with the two tested local exhausts. We can see that the N_2O concentration (armpits bioeffluents) was closest to zero under all tested conditions shown in Figures 3, confirming once again the high capturing efficiency of the VM. Since the manikin's arms were under the duvet, most of the N_2O tracer gas was sucked through the mattress before the gas to spread across the room. The concentration of the tracer gas in all measuring points using the VM with ESA=0.13 m^2 was the lowest compared with the other local exhaust. This result indicates that the size of the VM exhaust opening make a difference in the suction ability of the VM.

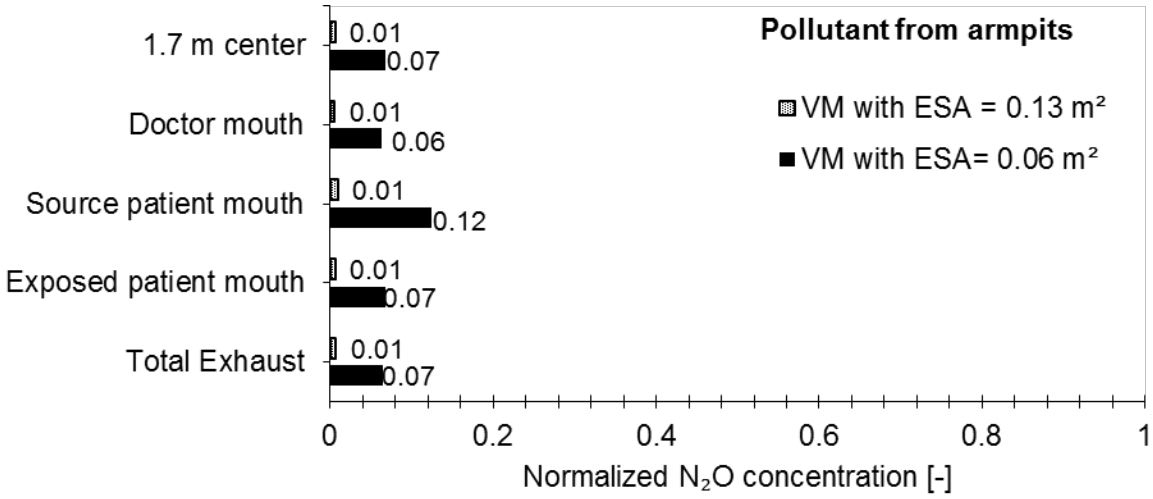
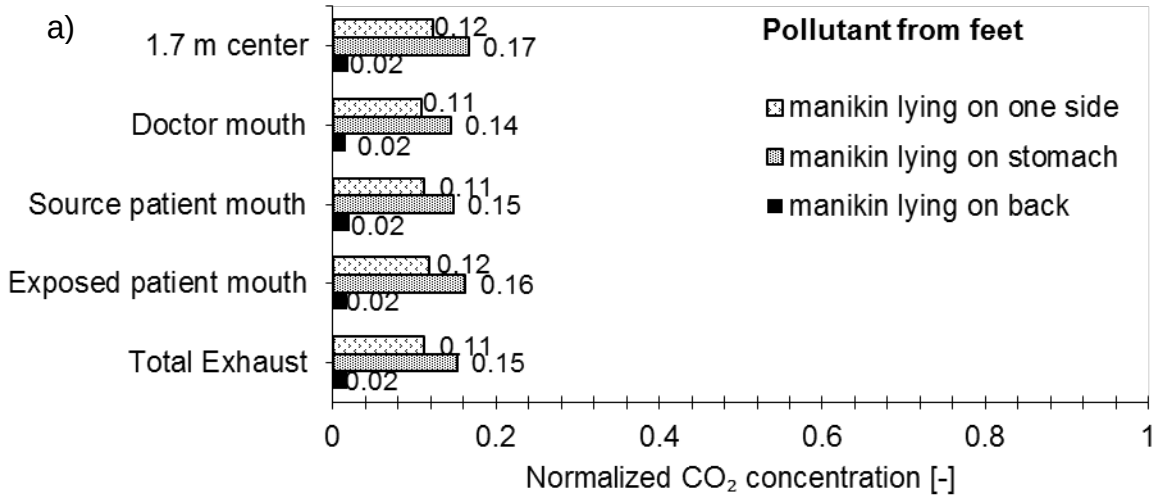


Figure 3. Comparison of the normalized concentration in the six measuring locations at the three different local exhausts of the VM and for the pollution source patient's armpits. The air change rate was 1.5 ACH and the "source patient" was lying on its back.

The impact of the manikin's lying position on the spread of the body bioeffluents when the VM was sucking air through its exhaust opening below the pelvis was assessed. The results for the lying positions on 'back', 'stomach' and 'one side' are shown in Figure 4. When the pollution source was manikin's feet, the lying positions on 'stomach' and 'one side' had a mild effect on the spread of the gas concentration, Figure 4a. In the lying on the back position both concentrations of the tracer gases (CO_2 and N_2O) were 99.9% discharged from the room (Figures 4a and 4b). The lying position had much stronger impact on the pollution distribution from the armpits, Figure 4b. We can see that when the manikin was positioned to lie on stomach the N_2O concentration in the room increased. In Figure 4b it can be noted that the normalized concentration (0.23) at the mouth of the "source patient" was less than at the other measuring locations (0.40 ± 0.02).



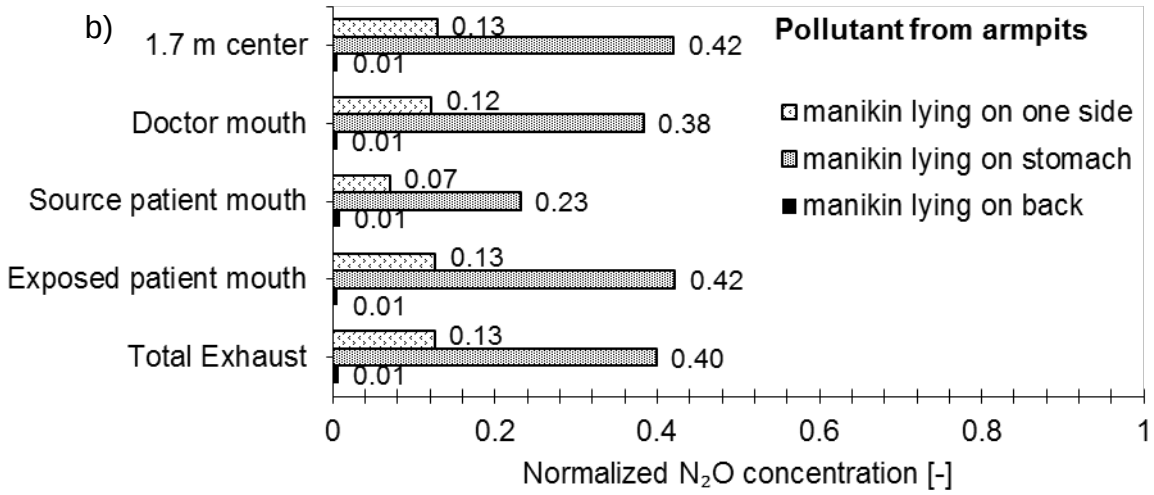


Figure 4. Comparison of the normalized concentration in the six measuring locations for the three different lying positions of the manikin and for the pollution sources: a) patient's feet and b) patient's armpits. The results were obtained at 1.5 ACH using the VM with ESA = 0.13 m^2.

The results of the present study show the ability of the ventilated mattress to successfully reduce exposure to gaseous contaminants when released from the body of a lying person. As shown in Figure 2, mixing ventilation alone is not able to completely dilute the bioeffluents emission from feet even when the ventilation rate in the room is 6 ACH. Similar result reported by Bivolarova et al. (2014) was obtained when the pollution source was the armpits of the patient.

In hospitals about 74% of all the building energy is utilized by the HVAC system (ASHRAE HVAC Design Manual for Hospitals and Clinics, 2013). For a general patient room ASHRAE Standard 170-2008 recommends overhead mixing type ventilation with up to 6 ACH. The findings in the current study show that the implication of the VM in hospitals can be an effective solution in minimizing the exposure to patients' bioeffluents at 4 times lower room ventilation rate. In Figure 2 the pollution concentration in the room was almost zero when the air change rate was only 1.5 ACH (27 L/s) and the ventilated mattress was operating at 1.5 L/s compared to the pollution concentration when the room was ventilated at 6 ACH (109 L/s) without the VM operated. It is therefore likely that such localized ventilation exhaust strategy as the VM will lead to substantial energy savings due to less air (only 1.5 L/s) used by the mattress to exhaust the air pollutants. Further studies, which take the energy use into account, will need to be undertaken.

The tested local exhausts of the mattress were both quite efficient in evacuating the generated bioeffluents before spreading into the room air. According to the results the most efficient local exhaust was the one under the pelvis with bigger surface area of 0.13 m^2 (Figure 3). There exist textile materials that are suitable to clean different gaseous contaminants including unpleasant odours generated from people (Bivolarova et al., 2014b, Mizutani et al., 2014). Thus the local exhaust of the VM can be made of such material and also provide cleaning of the polluted air. In this way the sucked polluted air by the VM will be cleaned locally and will be discharged back into the room allowing flexibility and further energy utilization.

The position of the source patient had effect on the spread of body emitted pollutants from armpits and feet. When the tracer gas was released from the armpits the concentration in all six measuring locations was the highest for when lying on stomach (Figure 4b). It is possible that when the manikin was position to lie on its stomach, bigger area of the exhaust opening of the mattress was blocked because of the different body curvature. This can be solved by designing a larger exhaust opening along the mattress.

CONCLUSIONS

The present study was designed to determine the effect of using the ventilated mattress to reduce the exposure indoors to body emitted bioeffluents. This study has shown that the VM is highly efficient advanced ventilation method for local pollution control. The VM combined with mixing ventilation at 1.5 ACH has proved to be more effective in reducing exposure to body contaminants compared to mixing ventilation alone at either 3 or 6 ACH. Thus, it seems that the use of VM in health care settings has a potential to reduce the energy consumption for such buildings.

The size of the exhaust opening of the VM and the lying position of the person on the mattress affect the Pollutant Extraction Efficiency of the mattress. It is recommended to use large local exhaust openings in the mattress.

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